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Multi Objective Optimization for Scheduling Repetitive Projects using GA

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Abstract

Projects that contain several identical or similar units are usually referred to as repetitive projects. Repetitive projects may be due to the uniform repetition of a set of activities throughout the project, or due to the physical layout of the project. Activities that repeat from one project unit to other project unit create a very important need for a project schedule that ensures the uninterrupted flow of crew from one unit to the next. This study will help to develop a method for scheduling repetitive projects with objectives of minimizing project duration, project cost and both of them with constraints of precedence relationships between activities, constraints of precedence relationships between units and constraints of the due date in which work should be complete.

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*Keywords:*Repetitive project scheduling;Genetic Algorithm.

Nomenclature

i	Activity
j	Project Unit
S_{ij}	Start time of activity i in unit j
F_{ij}	Finish time of activity i in unit j
d_{ij}	Duration of activity i in unit j
C_o	Original cost for the project

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C_D	Direct cost for the project
C_I	Indirect cost for the project
C_p	Penalty cost for the project
C_{ij}	Direct cost to complete activity i in unit j.
p_i	Penalty cost of activity i per day
l_{ij}	Lateness time of activity i in unit j
DT_{ij}	Due time of activity i in unit j
b	Indirect cost per day
T	Total duration for the project
C	Sum of direct, indirect and penalty cost for the project
d_i	Durations per unit quantity of work of activity i
w_{ij}	Quantity of work of activity i in unit j.
C_i	Direct cost per unit quantity of work of activity i
w_t	Weight assigned to the importance of duration
w_c	Weight assigned to the importance of cost

1. Introduction

The present industrial environment is characterized by companies facing competition from which customer requirements and expectations are becoming increasingly high regarding quality, cost and delivery times. To achieve these goals, an organization relies on the implementation of a number of functions together with scheduling which plays a very important role. Indeed, the scheduling function is intended for the organization of human and technological resource use in project industries to directly satisfy customer's requirements or demands issued from a project plan prepared by the company planning function. Its efficiency and failures will therefore highly affect the company's relationship with its clients. In repetitive project works, different resource options are available for each activity, and finding out the best option (assignment) to an activity is a major challenge for project managers as they want to take the decisions as quickly as possible. Within companies, this function has obviously always been present, but today it must face increasingly complex problems because of the large number of projects that must be executed simultaneously with shorter project durations.

2. Literature Survey

Available scheduling optimization models for repetitive projects can be grouped into two broad categories: (1) methods that minimize either project duration or cost and strictly follow crew work continuity (Selinger 1980 [1]);Mosenhli and El-Rayes [2]) and (2) methods that minimize either project duration and cost while allowing interruptions to crew work continuity (Russell and Caselton 1988 [3]; Hegazy and Wassef 2001[4]). All these methods are developed for optimizing only one objective at a time (i.e. minimize duration or cost). Therefore they can only produce a single optimal/ near optimal solution for the project being considered.

In many cases, these above methods are not easy to deal with complex projects due to enormous numbers of decision variables and nonlinear constraints. Hence, heuristic methods have been developed for scheduling projects in practice. R.Y. Huang and K.S. Sun presented an information about how to optimally plan and control resource allocation and activity alignment with regard to a repetitive projects [5]. Khaled Nassar presented a method that uses genetic algorithms to optimally assign crew to repetitive activities in order to minimize the overall project duration as well as the number of interruption days [6].Luong Duc Long and Ario Ohsato developed a new method for scheduling repetitive projects with several objectives such as minimize project duration, project cost, or both of them. The method deals with constraints of precedence relationships between activities, and constraints of resource work continuity[7]. Remon Fayek Aziz developed an optimization software (OSS) that is superior to existing optimization algorithms to minimize project duration, project cost, and working capital while maximizing its net present value [8].

Different models related to the exact and heuristic methods for scheduling repetitive project works problems are explained in the literature survey. But the mentioned methods either maintain work continuity to maximize learning effects, minimize idle labour and equipment time or it maximizes the net present value of the project. Very less number of literatures related to the multi objective optimization problems. Multi objective programming involves recognition that the decision maker is responding to multiple objectives. Generally objectives are conflicting, so that not all objectives can simultaneously arrive at their optimal levels. Another major challenge in repetitive project industry is the lagging of project due to different reasons which affects the clients. To avoid the financial losses of the clients, a penalty is being charged for each lagging day for each activity in all units. But no research work is conducted to mention this problem. So to prepare a multi objective optimization method for scheduling repetitive project works by considering the lateness penalty cost is very much important.

3. Problem Description

A company is doing same type of project works in different project units (e.g.,-Housing projects, pipeline networks etc.). Each project is divided into different activities and these activities are repeated in different project units [9]. Suppose a company is doing project works in ‘Q’ different project units and each project consists of ‘M’ different activities. Each project unit is modelled by an activity-on-node network, where a set of ‘M’ nodes represents M activities with their precedence relationships and this network is repeated in ‘Q’ repetitive project units. Normally a crew is assigned to each of the repetitive activities in the project unit network. The crew performs the same project unit activity consecutively and continuously [10]. Multiple crew options are available for each activity and each crew has an independent duration per unit quantity of work and cost per unit quantity of work. The selected crew shifts along different project units to perform the activity. The problem under study involves the minimization of objectives such as project duration, project cost, or both of them in a situation where if an activity is not completed in the particular due date, company should pay a penalty cost corresponding to that activity for every lagging days.

4. Mathematical Formulation

4.1. Objectives

- Minimize project durationZ_1=Min$\{\text{Max}\sum_{i=1}^{M}\sum_{j=1}^{Q}(S_{ij}+d_{ij})\}$ (1)

- *Minimize project cost*

C = $(\boldsymbol{C_D}+\boldsymbol{C_p}+\boldsymbol{C_I})$

$$\boldsymbol{Z_2} = \text{Min}\left(\left(\sum_{i=1}^{\boldsymbol{M}}\sum_{j=1}^{\boldsymbol{Q}}\left[\left(\boldsymbol{C_{ij}}\right)+\left(\boldsymbol{l_{ij}}\times\boldsymbol{p_i}\right)\right]\right)+(\boldsymbol{b}\times\boldsymbol{T})+\boldsymbol{C_o}\right) \quad (2)$$

- *Minimize combined effect of both project cost and project duration*

$$\text{TC} = \sqrt{((\boldsymbol{w_t}\left(\frac{(\boldsymbol{T}-\boldsymbol{T_{min}})}{\boldsymbol{T_{min}}}\right)^{\boldsymbol{2}})+(\boldsymbol{w_c}\left(\frac{(\boldsymbol{C}-\boldsymbol{C_{min}})}{\boldsymbol{C_{min}}}\right)^{\boldsymbol{2}})} \quad (3)$$

where

Overall objective TC is computed using planner-specified weights ($\boldsymbol{w_t}$, $\boldsymbol{w_c}$) that reflect the relative importance of project duration (T) and total project cost (C) respectively. The values of weight coefficients $\boldsymbol{w_t}$ and $\boldsymbol{w_c}$ are subjectively selected in the range [0.0, 1.0] by managers, and they should satisfy the equation ($\boldsymbol{w_t}$+$\boldsymbol{w_c}$=1.0).T and Care the project duration and the total project cost of the current solution.$\boldsymbol{T_{min}}$ and $\boldsymbol{C_{min}}$ are individual optimal objectives, and separately obtained by solving the model corresponding to the above objective functions 1 and 2 respectively. Equation 3 measures the shortest distance between the current solutions (C, T) and the idealsolution ($C_{min,}T_{min}$) in geometric sense. This equation stems from Zeleny's formula which is looking for the best compromise solution that would result in the minimum relative deviation from the ideal solution [11].

4.2 Constraints

- Durations to complete activity i in unit j

$$\boldsymbol{d_{ij} = d_i \times w_{ij}} \tag{4}$$

- Direct cost to complete activity i in unit j

$$\boldsymbol{C_{ij} = C_i \times w_{ij}} \tag{5}$$

- Lateness time of activity i in unit j

$$\boldsymbol{l_{ij}}=\text{Max}\ (0, \boldsymbol{F_{ij}}\text{-}\boldsymbol{DT_{ij}}) \tag{6}$$

- Precedence relationship among activities

$$\boldsymbol{S_{tj} + d_{tj} + lag_{t,i} \leq S_{ij}} \tag{7}$$

- Relationships among activities of different units

$$\boldsymbol{S_{ij} + d_{ij} \leq S_{i(j+1)}} \tag{8}$$

5. Methodology

Since obtaining exact solutions is found computationally intensive for these NP hard problems, an attempt is made to develop a heuristic based solution methodology for repetitive project work scheduling problem. One of the important heuristic techniques such as genetic algorithms is applied here because it is robust and has been proven theoretically and empirically to be able to efficiently search complex solution spaces [12, 13, 14]. GA procedure is explained in fig. 1.

5.1. Generation of initial population and design of chromosomes

The initial population of GA is randomly generated in this study. Here durations per unit quantity of work of activities are the decision variables which is assumed to be the genes of the chromosome in the populations. Each chromosome contain m decision variables and represents a potential solution corresponds to a generated solution. Chromosome size is depend on the difference between the maximum durations per unit quantity of work of activity (d_k^{max}) and minimum durations per unit quantity of work of activity (d_k^{min}) of all the resources in an activity. For example, if the decision variable is in a range of [d_k^{min},d_k^{max}], then chromosome size (number of bits (m) used for the decision variable) can be determined from the relation shown in equation 9.

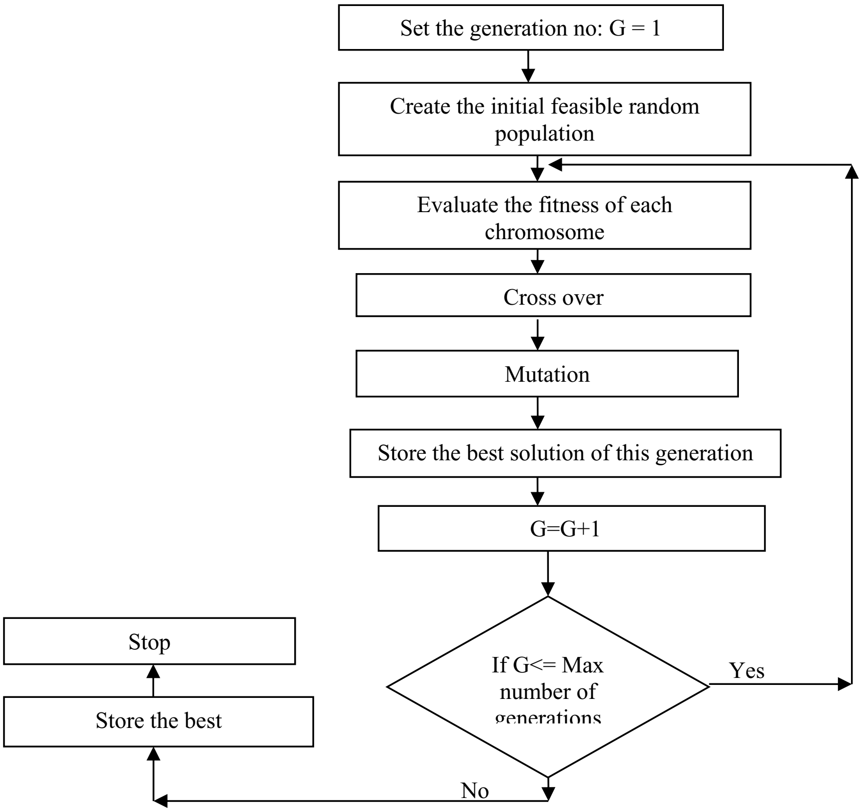

Fig 1. Mechanism of GA

$$2^{m-1} \leq (d_k^{max} - d_k^{min}) \times 10^w \leq 2^m - 1 \quad (9)$$

Here w is the required precision which implies that the range is $[d_k^{min}, d_k^{max}]$ divided into at least $(d_k^{max} - d_k^{min}) \times 10^w$ equal size ranges [12]. Then find out the crew option corresponding to each activity as per the genes of each chromosome and select d_k and C_k of each activity. An activity which has Q crew options are available, then a particular crew will be selected by the equation.

$$Y(k) = X(k) \times [Q/(2^\wedge(m) - 1)] \quad (10)$$

Where X(k) is the real value of binary substring of activity k and Y(k) is the option will be select. If (Q-1)≤ Y(k)≤ Q, then option Q will be select. With the help of scheduling algorithm find out the fitness of each chromosome in the population. A new population is created in the next generation with the help of selection, cross over and mutation operators and find out the optimum feasible schedule from different generations.

5.2 Scheduling Algorithm

The purpose of the scheduling algorithm is to calculate project duration and total project cost incurred by utilized project crews. The algorithm utilizes the following twelve steps to calculate project duration and project cost.

Steps:

- Calculate the duration (d_{kj}) and direct cost (C_{kj}) of each activity (k= 1 to n) in each repetitive project unit (j = 1 to u) based on the quantity of work and productivity of the selected crew option.
- Set start time for first activity in first repetitive project unit is zero (S_{11} = 0).
- Find out the start time of the initial activity in all successor project units (j = 1 to u) is ($S_{1(j+1)}$ =S_{1j}+ d_{1j}).
- Calculate the start time of remaining activities (i = 1 to m) in the first project unit ($S_{(k+1)1}$ = S_{k1} +d_{k1}).
- Calculate start time for activity i in repetitive project unit j according to the specified job logic between successor activities. For example, if the precedence relationship between two activities k and (k+1) is finish to start without lag time, activity (k+1) can start as soon as its precedence activity k is finished.
- Set start time (S_{ij}) for activity i in repetitive project unit j to be the latest of finish time of activity(i-1) in project unit j or activity i in project unit (j-1) if there is difference occurs between the mentioned finish times. This ensures that activity start time is set after its precedence activity is finished and its crew is available for construction.
- Calculate Finish time (F_{ij}) for activity i in repetitive project unit j (F_{ij} = S_{ij} +d_{ij}). Also calculate lateness time of activity i in project unit j (l_{ij}=Max (0, F_{ij}-DT_{ij}) where DT_{ij} is the due time of activity i in unit j in which work should be complete.
- Repeat steps 4 to 7 for the remaining activities in the project.
- Calculate direct cost, penalty cost and total cost for that schedule.
- Find out the combined effect of duration and cost.

6. Results and Analysis

6.1. Problem 1

To demonstrate the efficiency of the proposed technique, some problems are analyzed. The concrete bridge example which was first presented in Selinger [1] is analyzed in first problem. The project consists of four repetitive project units, and each includes the following activities in sequence: excavations, foundation, columns, beams, and slabs. Each repetitive activity is performed by a crew that moves from the first to the four project units sequentially. Different crew options are available for each activity is listed in table1. For consideration of project cost, the relationships between different crew formation options and direct costs are also assumed as in table 1. For solving this particular problem, some modification is given to Selinger's problem in which each activity in every unit has a particular due date in which work should be complete. Otherwise a penalty cost is added to the total cost of the project corresponding to every activity in each lagging day. The penalty cost is taken from random uniform distribution U[25,130]. For generating test instances of due dates for the above problem are characterized by a due date tightness factor (T) and a due date range factor (R) based on a study conducted by Lee and Pinedo (1997) and Pfund et al. (2008) in a job shop scheduling problem. The mean due date $\overline{\boldsymbol{d}}$ = $\boldsymbol{T_{min}}$(1-T) is calculated using due date tightness factor T = 0.3 which describes how close is the average due date to best make span. Here use a due date range factor R=0.25 to generate due date. The due dates are uniformly distributed over [(1-R)$\overline{\boldsymbol{d}}$,$\overline{\boldsymbol{d}}$] with probability T and over the interval [$\overline{\boldsymbol{d}}$,$\overline{\boldsymbol{d}}$ +($\boldsymbol{T_{min}} - \overline{\boldsymbol{d}}$)R] with probability (1- T). The indirect cost of Rs 25/day for the duration of the project and the initial cost of Rs1000 are used in this example. The crew option number corresponding to each activity is taken as the same order as shown in the question. The objective of this problem is to find out the best crew option corresponding to each activity that helps for minimizing the project duration; minimizing the project cost and minimizing the combined effect of both project duration and project cost.

For validation of the proposed method, the above problem is solved with complete enumeration technique using excel. A comparison of the results obtained by Problem 1 using GA method and complete enumeration technique is shown in table 2. The complete enumeration techniques prove the validity of the method developed using GA for solving single objective and multi-objective optimization of scheduling repetitive project works.

Table 1 Input data for first problem

	Quantity of work(square meter)				Crew option
Activity	Unit 1	Unit2	Unit 3	Unit 4	Duration/unit qty and cost/unit qty
Excavation	600	750	520	800	{1/48, 50}
Foundation	920	960	840	800	{1/80,80}, {1/64,70}
Columns	1450	1200	1800	1400	{1/80,70}, {1/112,100}
Beams	480	520	570	450	{1/56,65}, {1/32,90}, {1/40,80}
Slabs	0	1140	940	1200	{1/72,55}

Table 2.Comparison of Results obtained in GA method and Complete Enumeration Technique (Problem 1)

Objectives (Minimize)	GA Method			Complete Enumeration Technique		
	Duration(Days)	Cost (Rs)	Combined effect	Duration(Days)	Cost (Rs)	Combined effect
Duration	106.4865	1316773	-	106.4865	1316773	-
Cost	124.5679	1112478	-	124.5679	1112478	-
Combined effect	121.6975	1144315	0.103	121.6975	1144315	0.103

6.2 Problem 2

A project consists of five repetitive units and each unit includes 18 activities with the input data is taken from Luong Duc Long (2009,Page 500) [7]. Each activity in every unit has a particular due date in which work should be complete. Otherwise a penalty cost is added to the total cost of the project corresponding to every activity in each lagging day. The penalty cost is taken from random uniform distribution U[35,400]. The daily indirect cost of Rs 500 and the initial cost of Rs 4400 are assumed for this example. The due dates are generated by the same methods as in example one. Results obtained from GA method are shown in table 3.

Table 3 :Results obtained from GA (Problem 2)

Objective (Minimize)	Duration (Days)	Cost (Rs)	Combined effect	Crew option
Duration	75.9	130885	-	1-1-1-1-4-2-1-2-1-1-2-1-1-1-1-1-2-1
Cost	82.9	122359.5	-	1-1-1-1-3-1-1-3-4-2-3-1-1-1-1-1- 2-1
Combined effect	77	127029.3	0.0289	1-1-1-1-1-1-1-2-2-1-1-1-1-2-1-3-3-1

7. Conclusion

This paper presents a method for scheduling repetitive projects with objectives of minimize the project duration, project cost and both of them. In this work a penalty cost is added to the total project cost in a situation where a particular activity is not completed in the due date of that activity in a unit. The method consider the constraints of precedence relationships between activities, constraints of precedence relationships between project units and constraints of due date in which work should complete for each activity in every unit. The proposed method will help the project manager to select the best crew options to optimize the project duration and project cost in repetitive project works. The bridge construction problem from literature is analysed to validate the proposed method, and another problem is given to illustrate its new capability. It is observed that the proposed method can provide good solutions for optimizing the project duration, project cost and both of them.

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